Variability in 3D Acoustic Propagation in Shallow Water near Ocean Fronts

James H. Miller and Gopu R. Potty
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02881
Phone (401) 874-6540 fax (401) 874-6837 email miller@uri.edu

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LONG-TERM GOALS

The long term goals of our research are to:

1. Understand and model the 3-D propagation effects in shallow water and thereby explain some of the variations in acoustic field produced by the presence of shelf-break fronts and internal waves.
2. Apply our long range tomography inversion technique different locations and using different sources and improve the mode arrival estimation to improve it.
3. Revisit an earlier study to look into sea surface wave effects on modal travel times.

OBJECTIVES

- Use the transmissions from R/V Sharp, collected during the SW-06 experiment to explore any evidence of 3-dimentional propagation effects due to internal wave reflections and refraction.
- Use the data from Combustive Sound Sources (CSS) deployed by ARL-Texas to perform inversions for sediment parameters.
- To study the effect of the two tropical storms which passed through the SW-06 experimental area on the acoustic travel times and compare it with wave spectra collected near the experimental location.

APPROACH

The PIs (James Miller and Gopu Potty) took part in the SW-06 on the R/V Knorr and participated in the CSS deployments. The CSS data, collected on the WHOI Single Hydrophone Receive Unit (SHRU), was used to perform inversions for sediment properties. The inversions were performed using the long range sediment tomography technique developed earlier (Potty et al, 2000). A new time-frequency analysis technique (Dispersion based Short Time Fourier Transform) was developed to identify the modes and to calculate the modal arrival times. Graduate student George Dossot also participated in the experiments in the R/V Sharp. Transmissions from the R/V Sharp were used to

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14. ABSTRACT
The long term goals of our research are to 1.Understand and model the 3-D propagation effects in shallow water and thereby explain some of the variations in acoustic field produced by the presence of shelf-break fronts and internal waves. 2.Apply our long range tomography inversion technique different locations and using different sources and improve the mode arrival estimation to improve it. 3.Revisit an earlier study to look into sea surface wave effects on modal travel times.

15. SUBJECT TERMS

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investigate for the evidence of intensity fluctuations associated with internal wave interaction with acoustics. Modeling using a 3-D propagation code (3D PE) is being done to confirm these intensity fluctuations.

WORK COMPLETED

The data from SW-06 is being analyzed and preliminary results have already been presented at ASA meetings. A JASA- EL article has been published based on our inversions using Combustive Sound Sources (CSS). Graduate student George Dossot has been working on the data from R/V Sharp transmissions received on the WHOI- Shark VLA. He has completed the analysis of the data and has started modeling the propagation to include the effect of internal waves using a 3D Parabolic Equation code. He is expected to finish his dissertation work in a year. Additionally we are currently preparing manuscripts based on these results.

RESULTS

1. Geoacoustic inversions

Geoacoustic inversions are being carried out using data from Combustive Sound Sources (CSS). These sources were deployed by ARL- UT from R/V Knorr and acoustic data received at the WHOI-Single Hydrophone Receive Units (SHRU) is used for the inversions. The inversions were carried out using our modal dispersion based long range sediment tomography technique (Potty et al, 2000). A new time-frequency analysis technique – dispersion based short-time Fourier transform (Hong et al., 2005) was applied to the CSS data to calculate the individual modal arrival times as a function of frequency. These form the data for the inversion technique. Figure 1 shows the compressional wave speeds calculated using the modal arrivals and the standard deviations associated with the estimate. The inversions were compared with data from AHC-800 core and the Jiang- Chapman geoaoustic model (Jiang et. al., 2007) for the experimental area. Preston Wilson (ARL-UT), James Lynch and Arthur Newhall (WHOI) were collaborators in this study.

Compressional wave attenuation inversions were also carried out using our technique based on modal amplitude ratios (Potty et al., 2003). Figure 2 shows the results of the attenuation inversion. The attenuation estimates from the SW06 data compare well with the Shelf Break Primer inversions. The attenuation estimates from the East China Sea data is also shown in the figure. The rest of the data shown are from Stoll (1985). We are planning to extend our inversions using CSS to estimate shear properties of the sediments in the future. We have submitted a DURIP proposal (*Seafloor Shear Measurement Using Interface Waves*, Miller and Potty PIs) to acquire a Shear Measurement System (SMS) consisting of geophones and hydrophones and capable of collecting interface wave data. Using the dispersion characteristics of the interface wave data we propose to invert for shear wave speed. A mobile version of the CSS could be used to generate the interface waves.

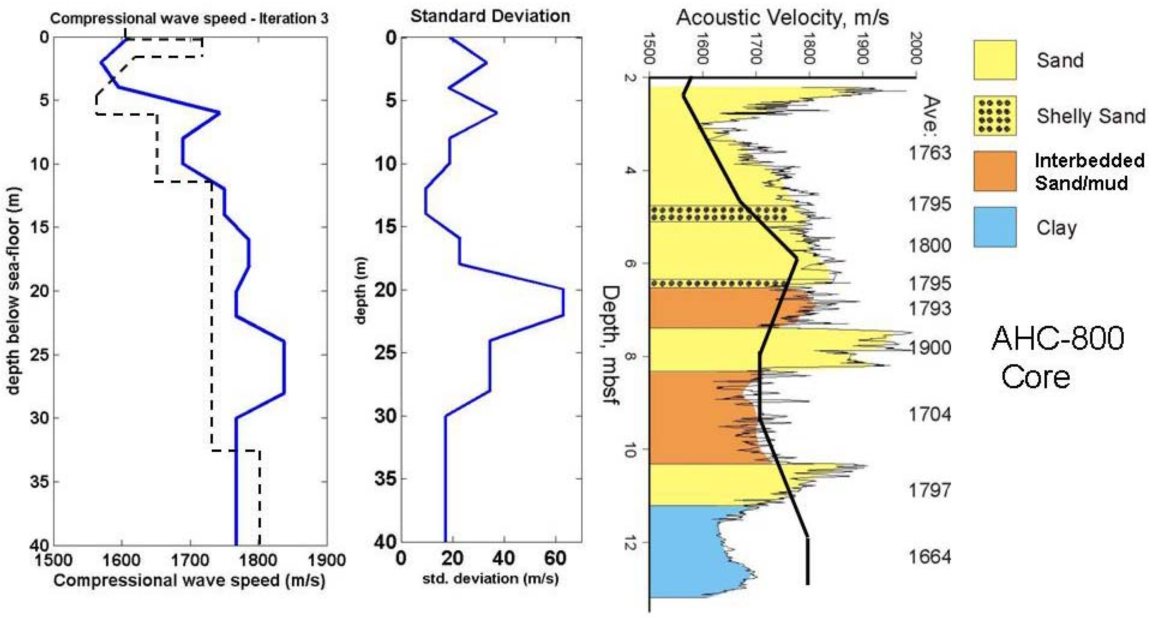

Figure 1: The inversion results for the top 40 m of the sediment (left panel) and the standard deviation (middle panel). The dashed line in the left panel is the Jiang-Chapman geoacoustic model (2007). The right panel shows the comparison of the inversion with data from AHC-800 core. The continuous black line in the right panel is the inversion result.

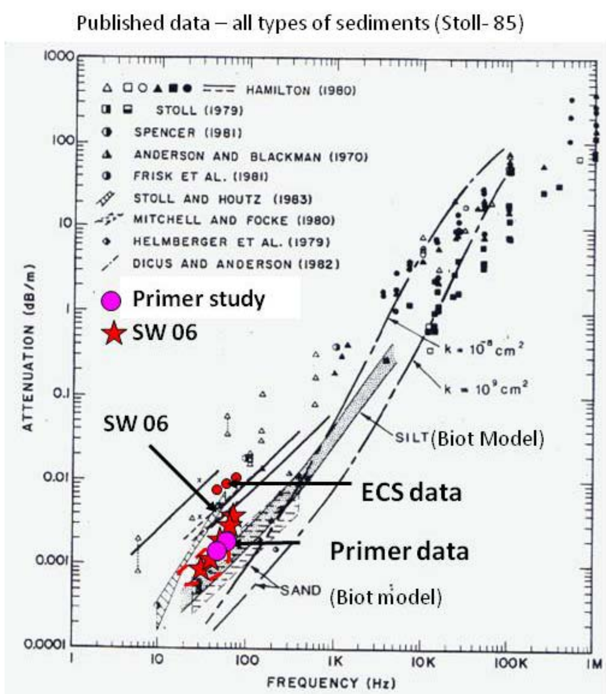

Figure 2: Attenuation inversions from SW 06 data compared with previous (ECS and Primer) inversions. The other data presented are from Stoll (1985).

2. Acoustic variability in the presence of internal waves:

George Dossot, as part of his doctoral dissertation research, has been examining the extreme variations of acoustic signals in the presence of internal waves. Specifically, we focus upon the intensity fluctuations of acoustic transmissions made by the R/V Sharp during the Shallow Water 2006 (SW06) experiment. Our ongoing research in this area involves close collaboration with the University of Delaware, The Woods Hole Oceanographic Institution, and the Naval Postgraduate School. Internal waves are known to cause extreme fades and intensifications of acoustic signals that pass through (or near) them depending on the angle between the propagating internal wave and the source-receiver pair. We are most interested in acoustic signals that pass parallel (or near-parallel) to the internal wave front because this configuration leads to a “ramping” of acoustic intensity which anticipates the arrival of the internal wave.

The R/V Sharp experienced over fifty internal wave events while participating in the SW06 experiment. Throughout the experiment, the R/V Sharp transmitted broadband acoustic signals using a J15 acoustic source at various angles in relation to the WHOI receiving arrays. This experimental configuration was purposefully done in order to examine the angle relationship between the source-receiver path and propagating internal waves. Environmental sensors aboard the R/V Sharp and on the deployed moorings were investigated for each event to determine the size and structure of the internal wave. These events were catalogued in a web-based archive and organized in a manner which prioritized promising datasets for acoustic analysis.

Almost all of the most promising datasets (4 of 5) yielded significant ramping of acoustic signals in anticipation of an approaching internal wave. This ramping phenomenon can be attributed to a three-dimensional version of the Lloyd’s Mirror effect; which causes acoustic signals to refract off the approaching internal wave front, resulting in multiple arrivals (and signal intensification) at the receiver. Additionally, as an internal wave passes over the source-receiver path, “ducting” can occur which traps the signal between internal wave solitons and yields extreme signal intensification.

In order to better understand the intensification phenomena, various intensity metrics are calculated as a function of depth, mode number, arrival index, frequency, or time. These intensity metrics can be statistically characterized in order to provide a global view of how the signals vary over the parameter we wish to investigate. As an example Figure 3 shows the broadband intensity measurements which occurred during internal wave Event 44 on 14 August 2006. These measurements show the intensity of each received broadband chirp signal, integrated over the duration of the chirp, on each VLA hydrophone, and over time. The signals are match-filtered and normalized such that the overall mean is one. These intensity measurements are compared to the sound speed profile at a point halfway between the source-receiver path (Environmental Mooring SW32). In this instance, both ramping and ducting phenomena are evident.

To understand depth dependence, Figure 4 also shows intensity measurements for Event 44, but distilled at four separate depths. We see the ramping is most evident at the middle depths – where internal wave activity is predominant. The histograms show significant variability just below the thermocline, and also at the very bottom. The bottom variability is surprising, and may be due to warm water bottom intrusions that are known to precede the internal wave. We have also investigated a host of other metrics, including frequency and modal dependence, in order to better understand the intensity variations that occur in the presence of internal waves. Our ongoing and future work involves modeling these events to replicate (and better understand) the ramping phenomena and the depth dependant variability.

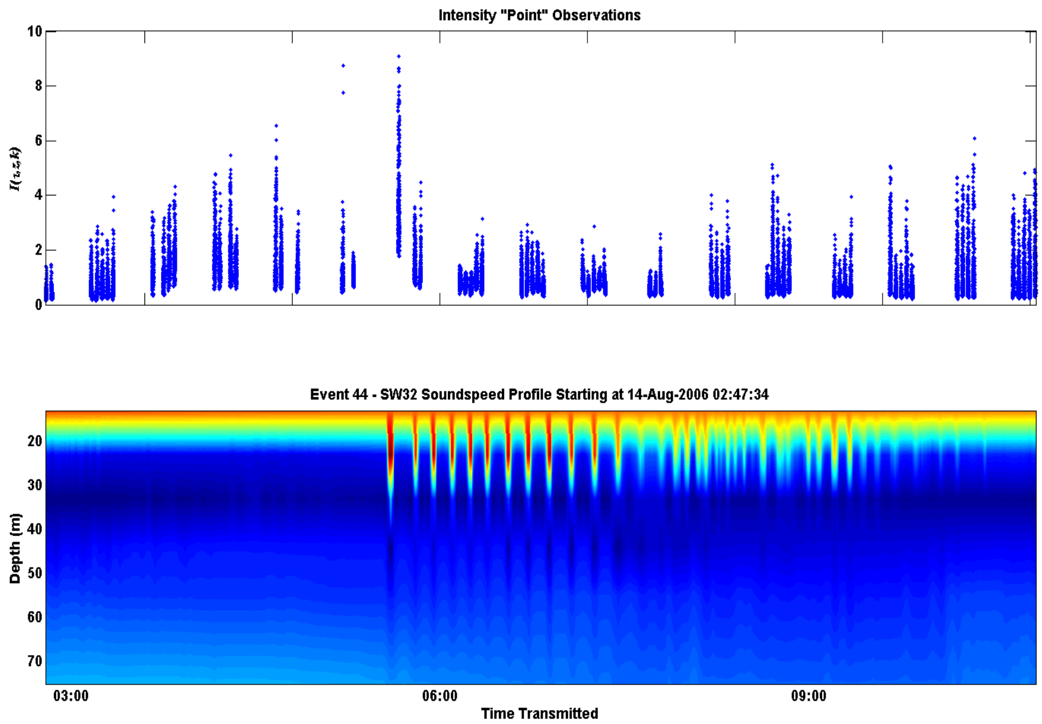

Figure 3: Broadband intensity measurements during internal wave Event 44. These measurements show the intensity of each received broadband chirp signal, integrated over the duration of the chirp, on each VLA hydrophone, and over time. The bottom panel shows the sound speed profile at a location along the propagation path.

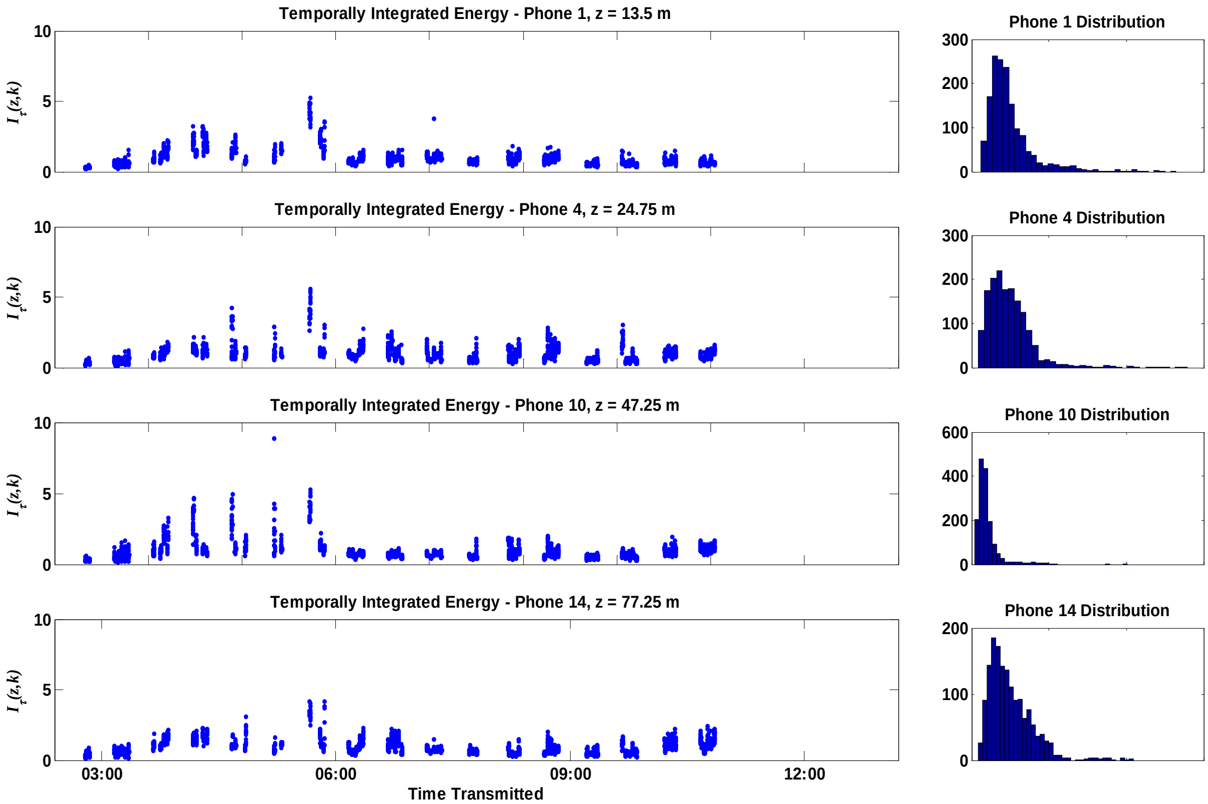

Figure 4: Intensity measurements for Event 44 at four separate depths (13.5 m, 24.75 m, 47.25 m and 77.25 m) shows that ramping is most evident at the middle depths – where internal wave activity is predominant. The histograms show significant variability just below the thermocline, and also at the very bottom.

3. Sea surface wave effects on modal travel times

During the SW-06 experiment two tropical storms (Ernesto and Florence) passed by the experimental area in September, 2006 which provided high seas. We studied the wandering and spreading of the acoustic normal modes before, during, and after the passage of these tropical storms. The theoretical framework for this study was based on previous work by Miller et al. (1989). Using the data from the 224 Hz and 400 Hz tomography sources received at the WHOI VLA/HLA we calculated the spectra of the travel time variations. These results will be compared with ocean wave spectra collected during the experiment at the location. This study was conducted by a graduate student, Gregor Langer for his Master's thesis research. We are preparing a manuscript based on this study for publication.

IMPACT/APPLICATIONS

The inversion scheme using explosive sources is suitable for rapid estimation of acoustic properties of sediments in shallow water. This method is cost effective as a single sonobuoy and air-deployed explosives can provide the data. Using multiple sources and receivers sediment properties would allow an area to be mapped. 3-D propagation effects are important to naval applications as it can cause fluctuation in the acoustic field of the order of 5 to 10 dB.

TRANSITIONS

The sediment parameters obtained by this inversion will compliment the forward modeling efforts. The sediment tomography technique is suitable for forward force deployment when rapid assessment of environmental characteristics is necessary. In addition to naval air ASW applications using sonobuoys and SUS charges, this technique would be compatible with Navy special operations involving autonomous vehicles.

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HONORS/ AWARDS/ PRIZES

James H. Miller was elected to the Executive Council of the Acoustic Society of America.

Gopu Potty was nominated to the Advisory Committee and Technical Program Committee of the International Symposium on Ocean Electronics organized by the Cochin University of Science and Technology in Cochin, India (November 18-20, 2009).